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An ultraviolet high-energy Thomson scattering probe beam has been implemented on the Omega laser facility at the University of Rochester. The new probe operates at a wavelength of 264nm, with a maximum energy of 260J in a pulselength of 1ns. The probe is focused with an F/6.7 lens to a minimum focal spot of 40μm within a pointing tolerance of <50μm. Data obtained from this probe beam has provided new diagnostic information on plasmas relevant for inertial confinement fusion and atomic physics studies.

PACS numbers:

In recent years Thomson scattering probe beams have been implemented on a number of large laser systems as a diagnostic of temperature and ionization conditions inside dense plasmas [1]. The information obtained from Thomson scattered can be used to test the accuracy of hydrodynamics and atomic physics models [2]. To facilitate this work an independent 4ω probe has been implemented on the Omega laser system [3]; the capabilities of this probe will be described together with some examples of Thomson-scattering data obtained during the commissioning of this diagnostic.

The 4ω probe beam is derived from the existing 2ω probe beam on the Omega laser (beamline 25). The 2ω pulse (diameter = 280mm, maximum energy on target = 400J in 1ns) currently propagates via three 2ω transport mirrors to a diagnostic port that has been converted to hold a 300mm diameter aspheric focusing lens [4]. To convert the probe to the fourth harmonic, a 300mm-diameter type I KDP crystal, thickness 10mm, was inserted after the final 2ω turning mirror in the system. The 4ω beam was aligned to the existing 1ω and 2ω systems using a 4ω alignment laser injected just before the 4w KDP conversion crystal as shown schematically in figure 1. A diagnostic wedge sent a 4% reflection of the 2ω and 4ω beams to an uncoated full aperture spherical focusing mirror with 3.125m focal length. A CCD camera placed at the focus of this mirror was then used to achieve overlap of the two beams in the far field, ensuring that the 4ω beam was aligned to the 1ω and 2ω alignment laser and thus to the Omega system itself. On system shots the far field alignment system was protected by placing a pair of calorimeters in front of the cameras, which in addition characterized the 2ω and 4ω beam energy on each shot.

Angular tuning of the KDP crystal was first characterized offline using a low energy doubled ND: YLF laser system operating at a wavelength of 527nm with a pulse length of 200ps and maximum pulse energy of 1mJ. This system was used to locate the optimum tuning angle and determine the sensitivity of the angular phase matching with ambient temperature. This information was used to dynamically optimize tuning in case of temperature variations in the Omega target bay. Optimum conversion as a function of tuning angle was determined *in situ* using a series of system shots, as shown in Figure 2. It can be seen from this figure that the peak of the crystal rocking curve occurred at an incident angle of 5.6 mrads. Monitoring of the crystal temperature allowed modifications to the angular according to any fluctuations of ambient temperature. Conversely, control of the energy delivered to the target was also achieved by manipulating the angular tuning around the narrow conversion curve (full width half maximum = 1.5mrads).

Focusing of the beam was verified using a retro-reflection system from a surrogate spherical target located at the center of the target chamber. Determination of any residual pointing offset between the 4ω alignment beam and the pulsed beam was achieved by first focusing the alignment beam onto a 1.6mm diameter steel ball located at chamber center, and then taking an x-ray image when the pulsed beam was focused to the same location on the ball. The X-ray emission (above 1keV) was imaged using a pinhole camera filtered with 100μm of Beryllium, onto a CID camera. X-ray pinhole data from the focal spot produced by focusing 100J of 4ω energy in a 1ns duration pulse onto the 1.6mm ball is shown in Fig.3. Six other Omega beams were also aligned onto the ball to provide spatial fiducials on the image; these are the x-ray spots that can be seen around the 4ω beam spot. Using a reduction algorithm the position of the x-ray image from the probe with respect to these five fiducials gave a relative pointing error of 50μm for the system. Further shots were taken with this diagnostic arrangement to locate the position of the optimum focal point. The smallest focal spot measured by this system 40μm ±10μm

The Thomson-scattering diagnostic was implemented to diagnose thermal temperatures in laser produced plasmas. Thomson collected light was collected by a fused silica F/10 lens mounted in TIM-2.The angle between TIM-2 and the input port (P9) of the Thomson probe was 79°. The lens was protected from plasma debris by a 1mm fused silica debris shield. The collected light scattered from the focal region was then transported by a series of turning mirrors to a 1m (McPherson) spectrometer, located approximately 10m from the target chamber. The focal region was relayed onto the slit of the spectrometer with a lens of the same focal length as the collection lens, giving a 1:1 magnification ratio. The spectrometer used a 2400l/mm grating operated in 1st order with a 200μm wide entrance slit. The output of the spectrometer was directly coupled to a streak camera, which gave a dispersion of 0.011 nm/pixel dispersion, spectral resolution of 0.5A and a temporal resolution of 50ps.

During this commissioning experiment good quality Thomson-scattering spectra were obtained during probe interactions with high Z plasmas, vacuum and gas filled hohlraums, and gas-bag targets. These targets were heated to keV temperatures by a subset of the Omega beams. A typical example of 4ω Thomson data is shown in Figure.4(a), obtained from 4mm diameter gas bag filled with 1 atmosphere of Krypton. In this figure the time axis runs form left to right and wavelength increases downwards. The gas bag foil was heated by two sets of beams each 1ns long. Thomson scattered light is observed just after the start of the probe beam and is dominated by the two symmetric lobes either side of λ_0. This is the ion acoustic feature characteristic of thermal Thomson scattering. In principal, the electron, ion temperature or average ionization of all the species in the plasma can be obtained by fitting a kinetic model to this spectrum. In this case the kinetic model was fitted to the spectrum at 500ps after the start of the probe pulse, as shown in Fig.4(b). The fit gives T_e= 2 keV ± 20%, Te=T_i for this data. For these conditions the average ionization of Z* = 26 for the Krypton species was obtained from calculations. This result appears to be in good agreement with preliminary hydrocode simulations of this interaction, which give an electron temperature of 1.6keV for these conditions [5]. This data confirms the utility of 4ω Thomson scattering for providing accurate and independent measure of electron temperatures in dense hot plasmas. Ore details will be published in a more specialized journal.

In summary a new 4ω Thomson-scattering diagnostic probe has recently been demonstrated at the Omega laser facility. The energy, intensity and pointing accuracy and have all been carefully characterized. This diagnostic has already begun to produce high quality data on temperature conditions in dense, high Z plasmas, providing information that can be used to benchmark atomic physics models.

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References

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Figures:

1. Schematic of Probe beam layout
2. Rocking curve for conversion from 2w to 4w for 300mm diameter, 10cm thick KDP. Maximum conversion was close to 70%. At peak conversion the system produced an energy on target of 260J of 264nm light in a 1ns pulse.
3. X-ray image of pointing and focusing tests. Focal spot was pointed to within 50μm of alignment reference and the minimum spot size was 40μm
4. 4ω Thomson scattering data for Krypton gasbag, showing 2keV electron temperature just after heater pulse turns off

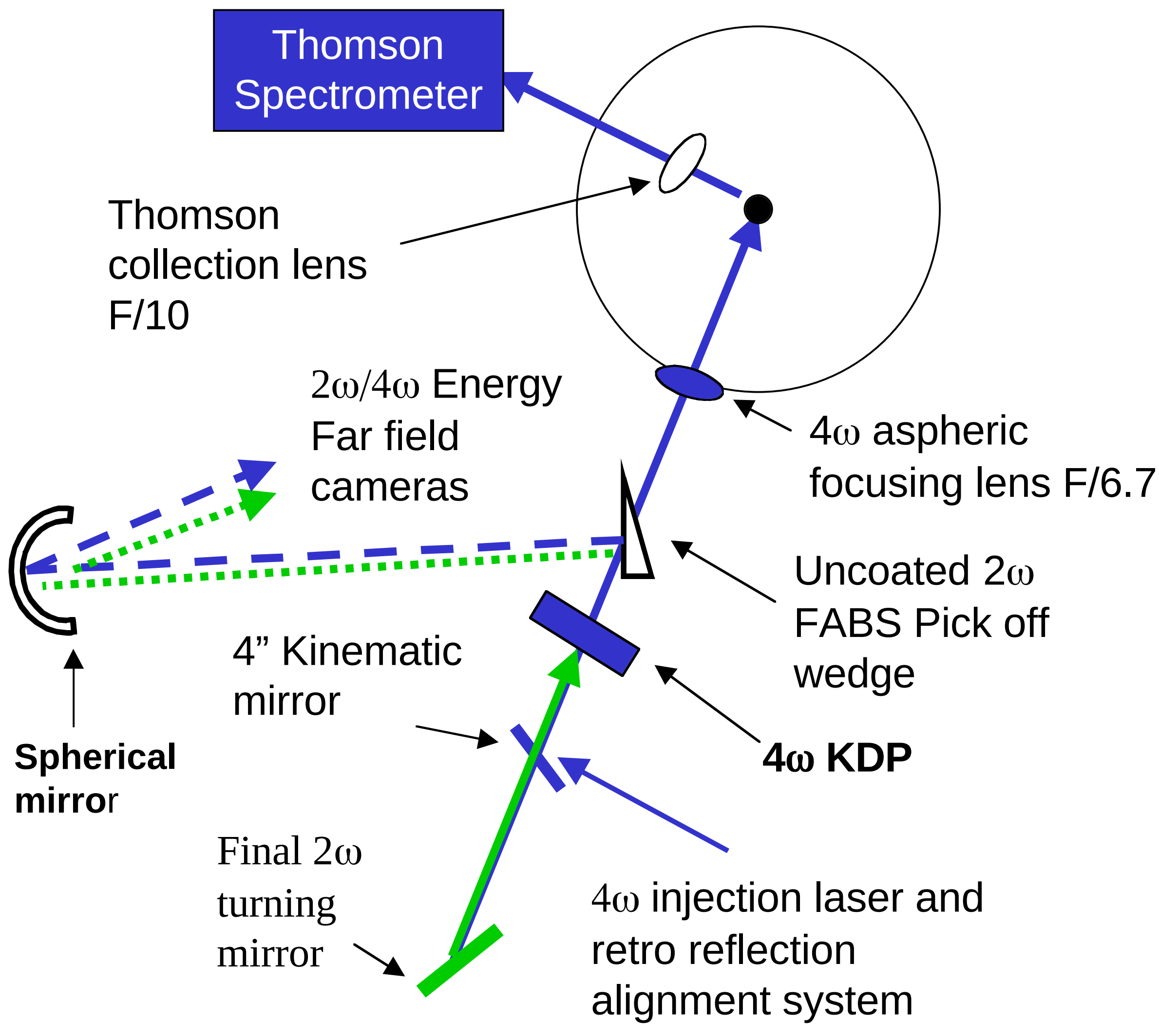
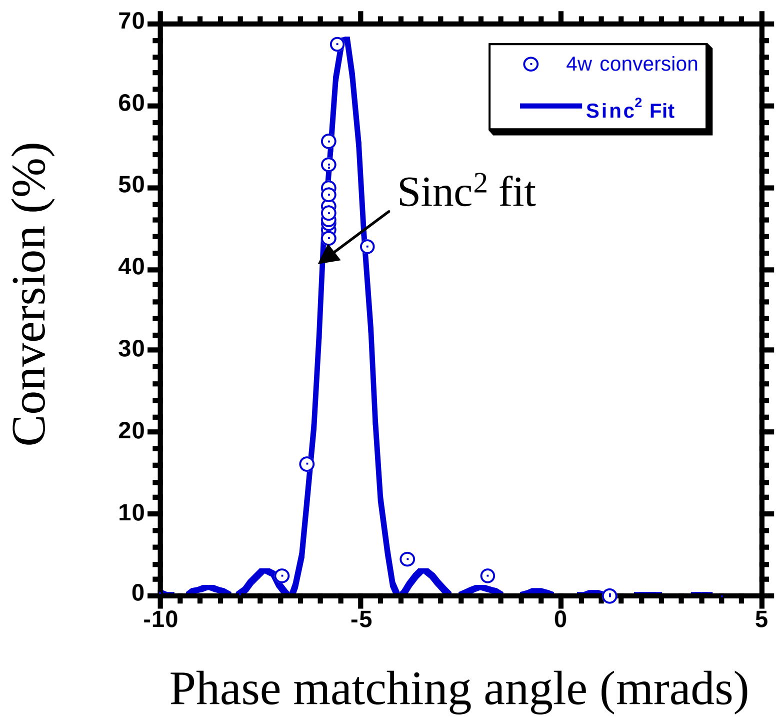

Thomson
Spectrometer
Thomson
collection lens
F/10
2ω/4ω Energy
Far field
cameras
4ω aspheric
focusing lens F/6.7
Uncoated 2ω
FABS Pick off
wedge
4” Kinematic
mirror
Spherical
mirror
4ω KDP
Final 2ω
turning
mirror
4ω injection laser and
retro reflection
alignment system

Figure 1



70
60
50
40
30
20
10
0
-10
-5
0
5
4w conversion
Sinc^2 Fit
Sinc^2 fit
Conversion (%)
Phase matching angle (mrads)

Figure 2

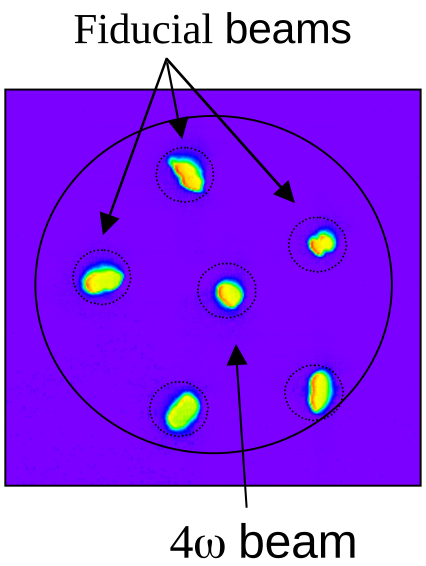


Figure 3

a)

b)

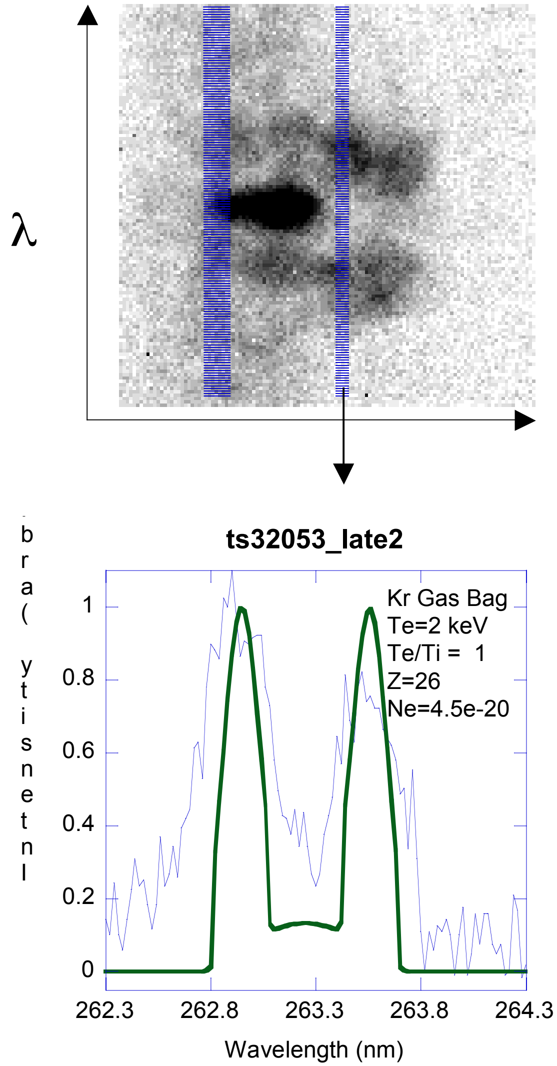

λ
ts32053_late2
Kr Gas Bag
Te=2 keV
Te/Ti = 1
Z=26
Ne=4.5e-20
Intensity (arb.
1
0.8
0.6
0.4
0.2
0
262.3
262.8
263.3
263.8
264.3
Wavelength (nm)

Figure 4